Temporal and Spectral Dimensions of Shortwave Cloud Radiative Effects from Observations and Models

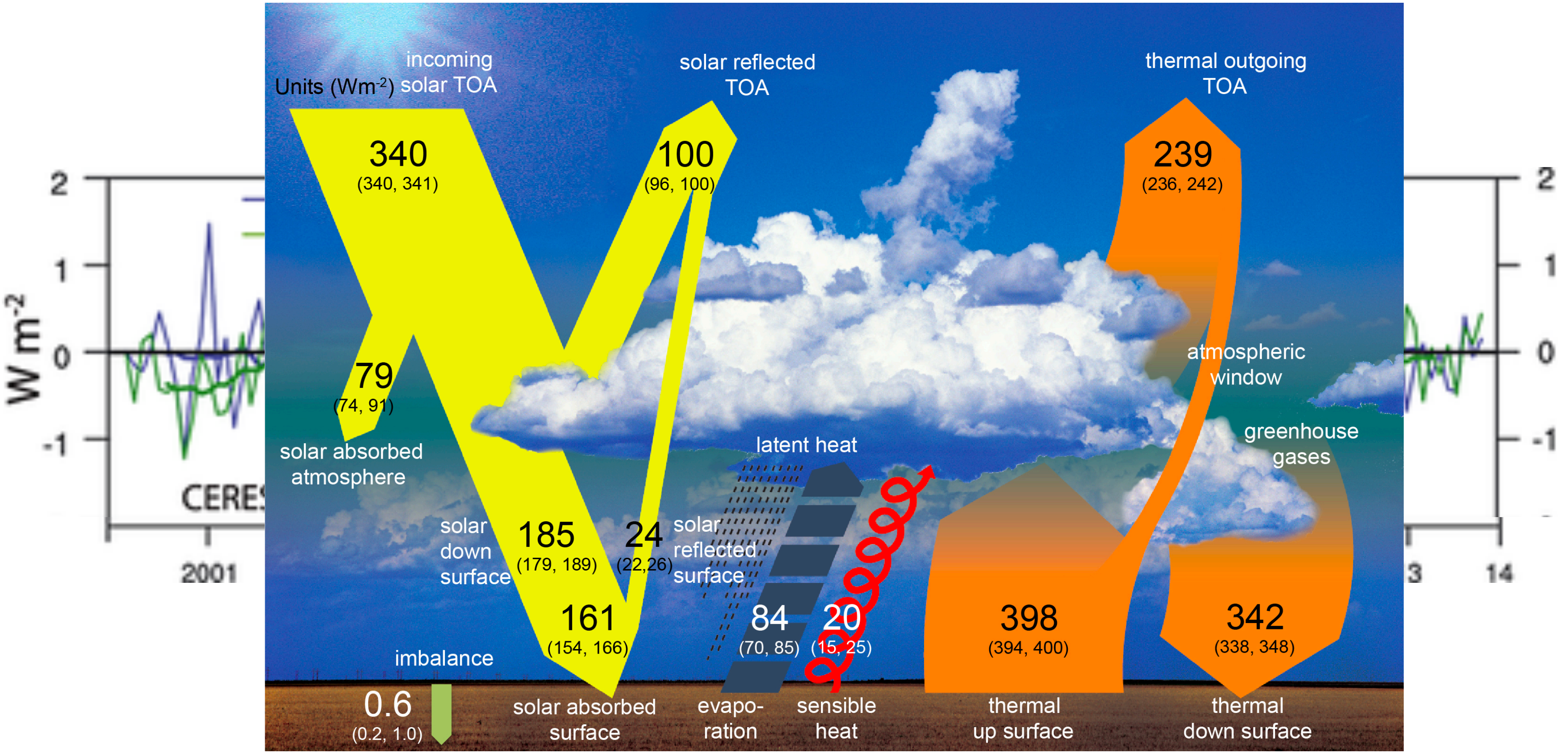
Daniel Feldman[1], Wenying Su[2], Steve Lorentz[3]
Bill Collins[1,4], Yolanda Shea[2], Bruce Wielicki[2]

1 Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory
2 NASA Langley Research Center
3 L-1 Standards and Technology, Inc.
4 University of California-Berkeley, Earth and Planetary Science Department

2019 CERES Fall Science Team Meeting
October 30, 2019

Scientific Motivation

- The scientific understanding of how atmospheric processes interact to stabilize planetary albedo on interannual time-scales is not mature.
- Can measurements and models be used to advance the understanding of this phenomenon?

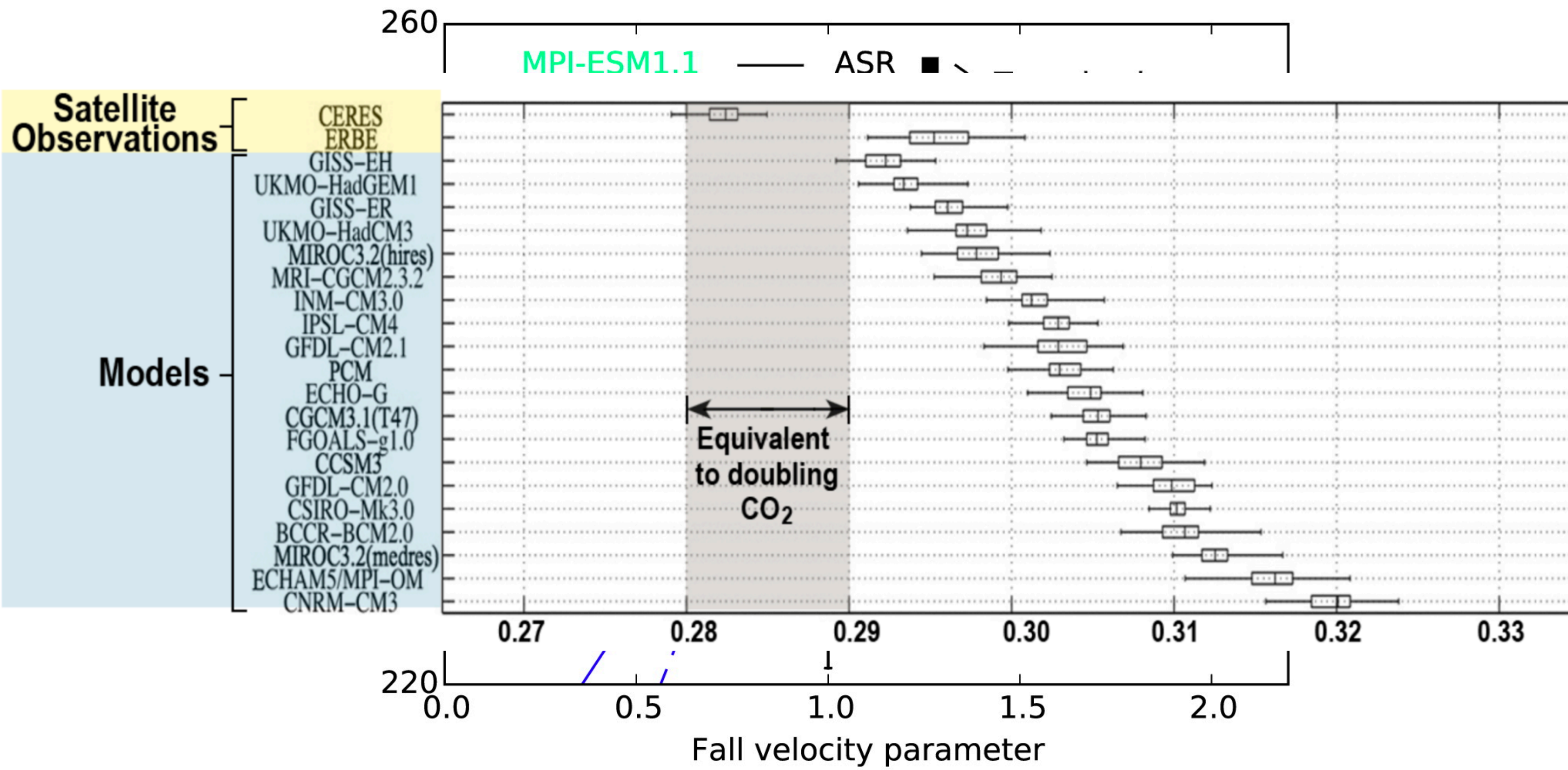


Trenberth et al, JGR, 2015
IPCC AR5, 2013

Scientific Motivation

- The tuning of models with measurements complicates the advancement of this understanding.

- Within a range of climate states, that has yet to be determined, the tuning process ensures that models can provide no information about the stability, or lack thereof, in planetary albedo.



Overview

- There are two parts to this talk, where we seek to look at the shortwave reflected energy budget: the temporal and spectral components of the Earth’s albedo.

- These provide alternative vantage points to understand TOA radiative fluxes in order to look into how they can be used to confront models.

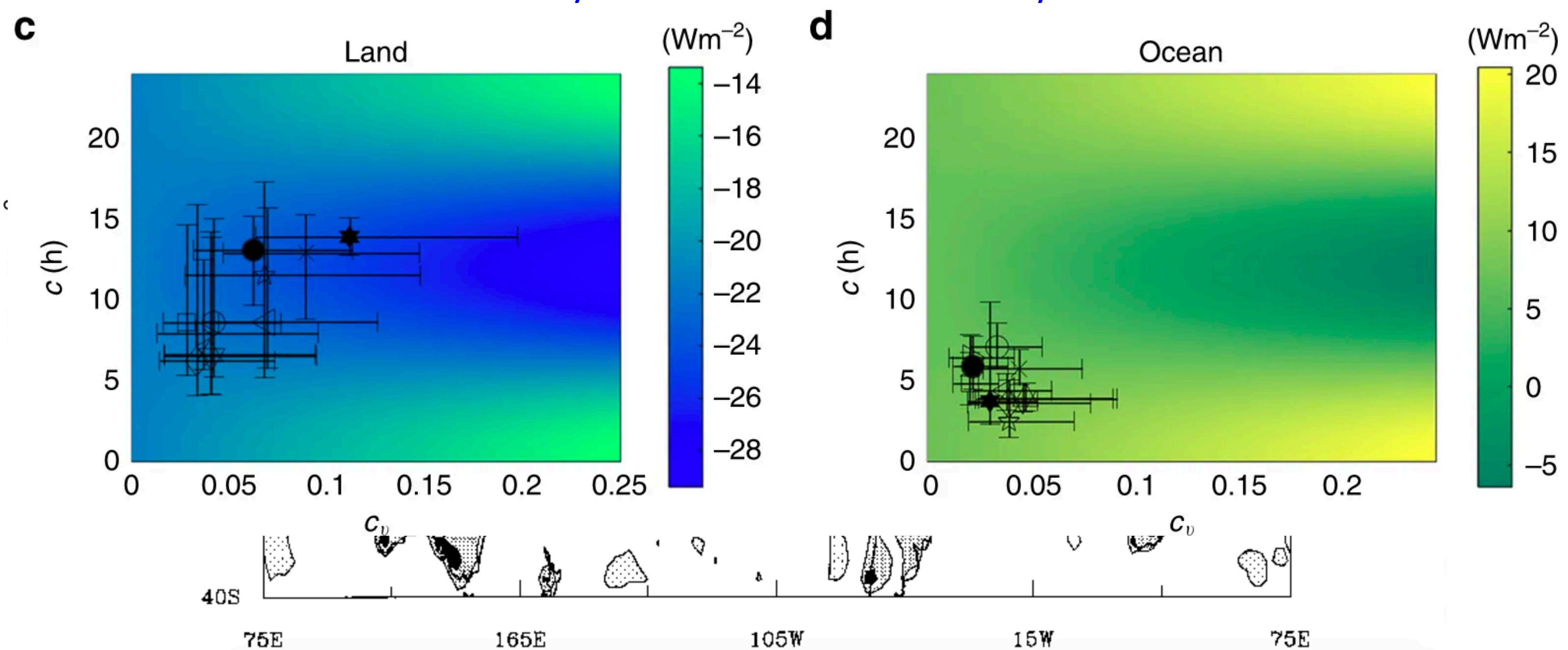
- In the first part, we will use a relatively novel set of high-frequency observations to test if there are potential biases in the development of diurnally-averaged fluxes, and then see what that means for measurement-model intercomparisons.

- In the second part, we will explore what we could potentially learn from spectrally-resolved albedo measurement to understand if models can achieve the right albedo for the wrong reason.

Part I: Importance of the Diurnal Cycle of Clouds

- Biases in albedo can arise from surface reflection and time-mean cloud properties. One understudied source of bias is cloud diurnal cycles.
- Diurnal variability in clouds modulates the diurnal cycle of solar insolation.
- Monthly-mean shortwave fluxes are influenced unevenly by the diurnal cycle of clouds.

Cloud Diurnal Cycle Contribution to Monthly-Mean SW Flux

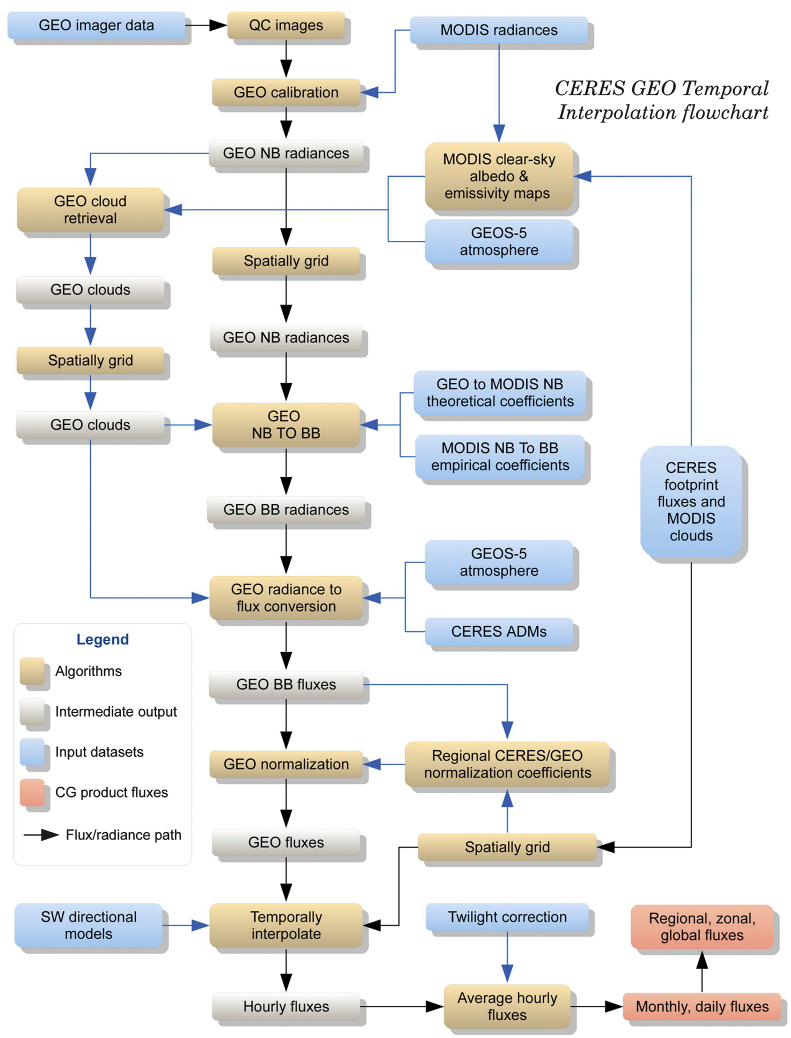


Yin and Porporato, Nature Communications, 2017

Bergman and Salby, Journal of Climate, 1997

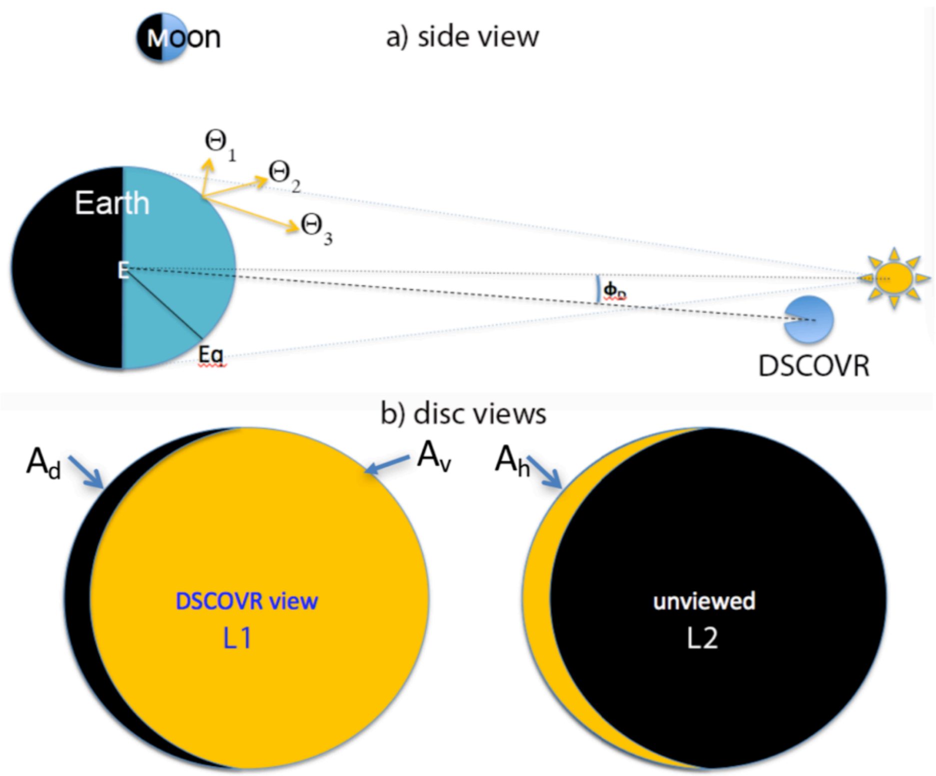
RSR Diurnal Variability

- But how well do we know diurnal variations in SW radiation?
- CERES monthly-averaged flux estimates require an estimate of the diurnal cycle in RSR, even though observations are made at fixed local solar hours.
- The process-chain for diurnal filling has numerous components, relying primarily on a network of geostationary cloud observations.
- The diurnal filling of fluxes has not independently tested outside of GERB.
- Independent tests of CERES SYN are needed.



Observations from DSCOVR

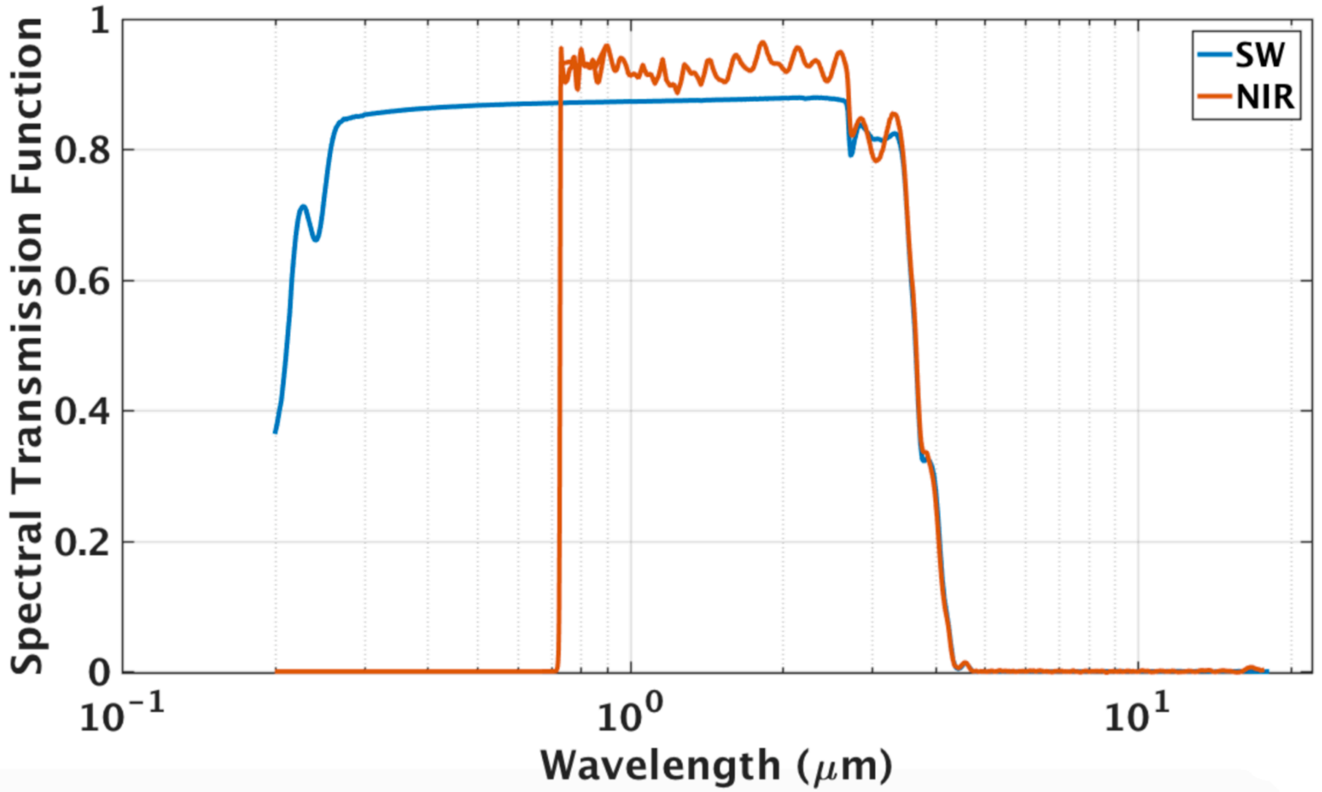
- Launched in 2015, the Deep Space Climate Observatory orbits about the L-1 point between the Earth and the Sun.
- Continuous observations of narrow-band imagery from EPIC and broadband Earth-as-a-pixel radiance from NISTAR are provided.



NISTAR/EPIC Observations

- Launched in 2015, the Deep Space Climate Observatory orbits about the L-1 point between the Earth and the Sun.

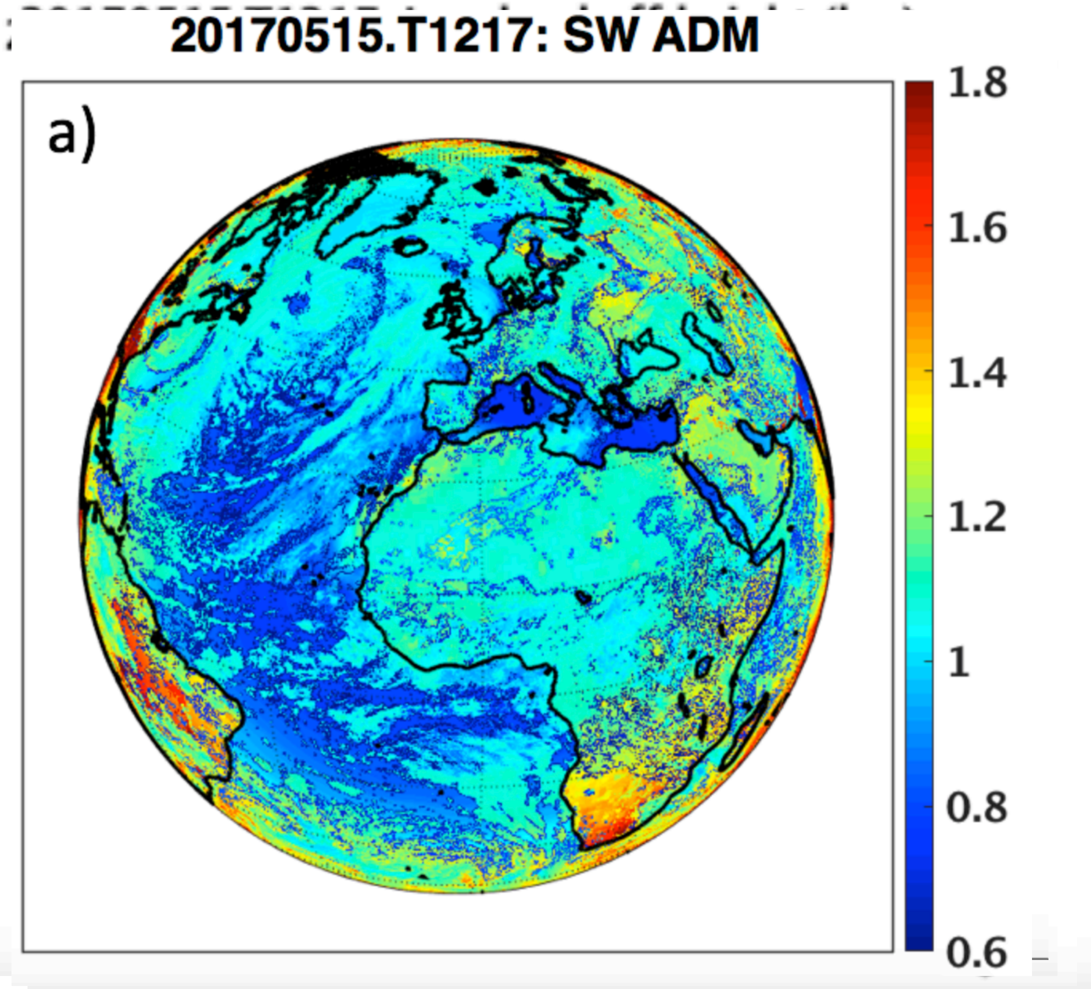
- Continuous observations of narrow-band imagery from EPIC and broadband Earth-as-a-pixel radiance from NISTAR are delivered from DSCOVR.



Su et al, AMTD, 2019

Converting Radiances to Fluxes

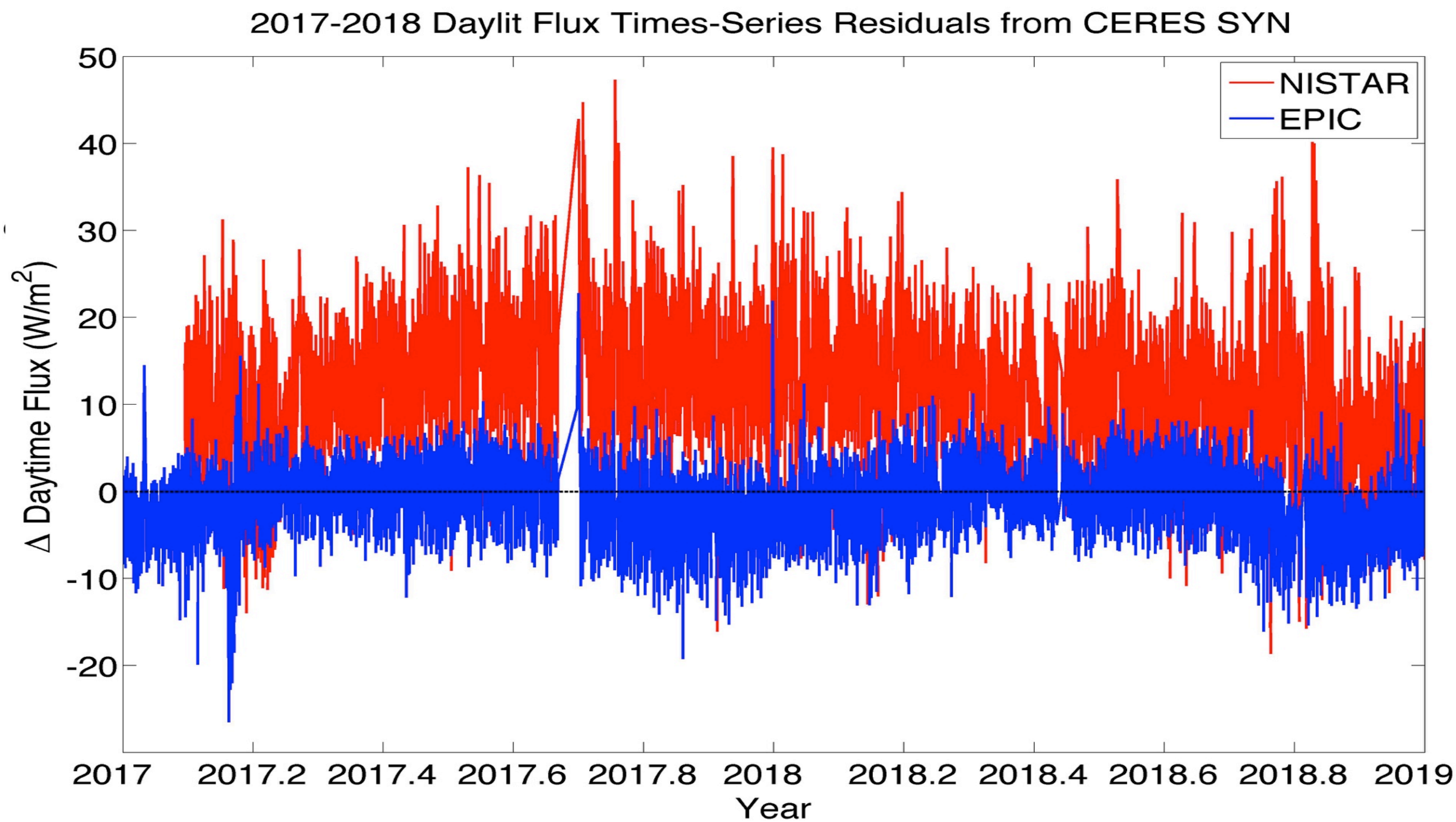
- Su et al, 2019 have developed algorithms for converting those observations to shortwave fluxes, using the CERES ADM infrastructure for scene identification.



Su et al, AMTD, 2019

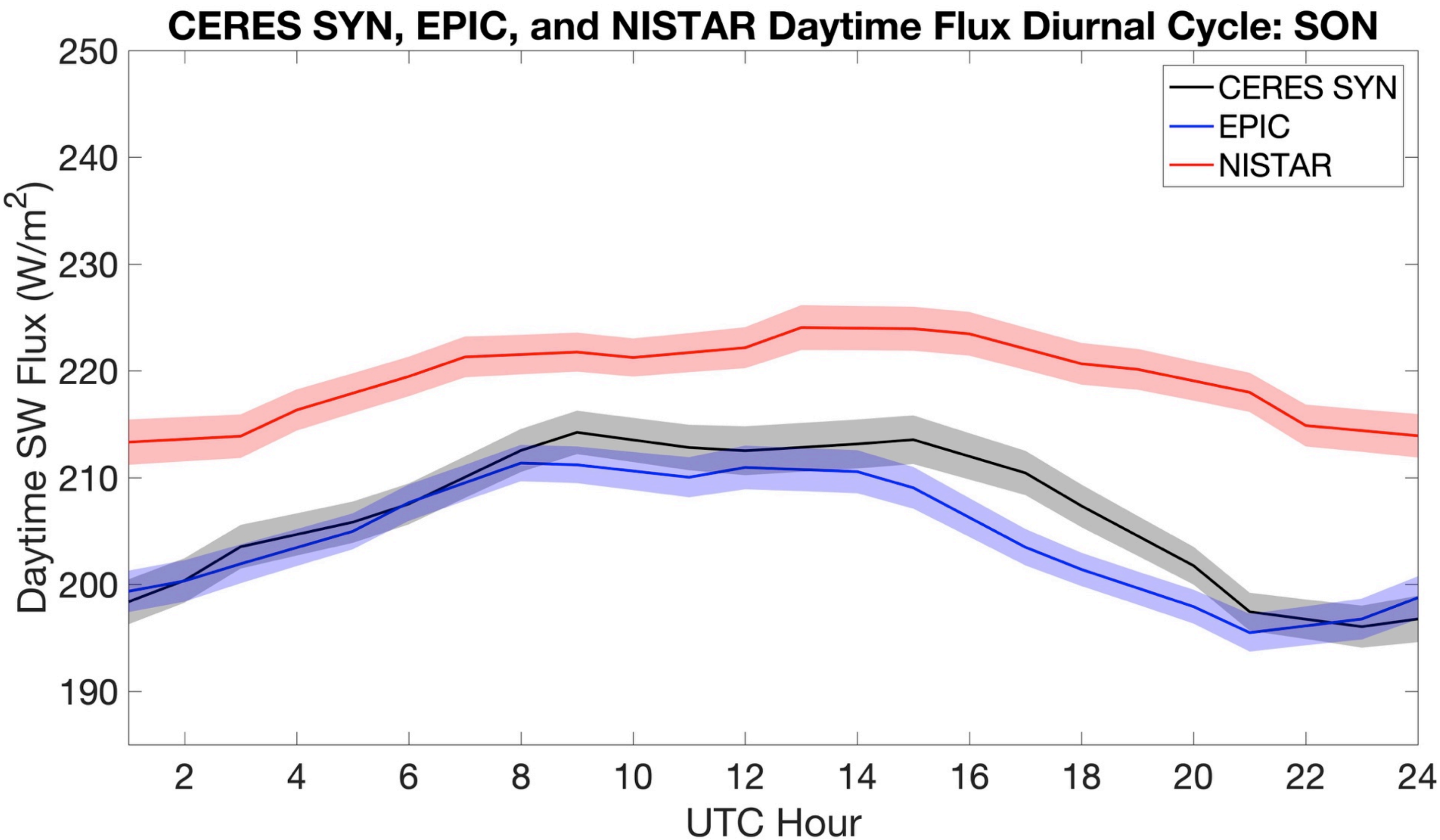
Observations of RSR Variability

- Two years of daytime TOA reflected shortwave radiation (RSR) from CERES Synoptic product, and derived from EPIC imagery and NISTAR radiometry reveal many modes of variability and a NISTAR bias.



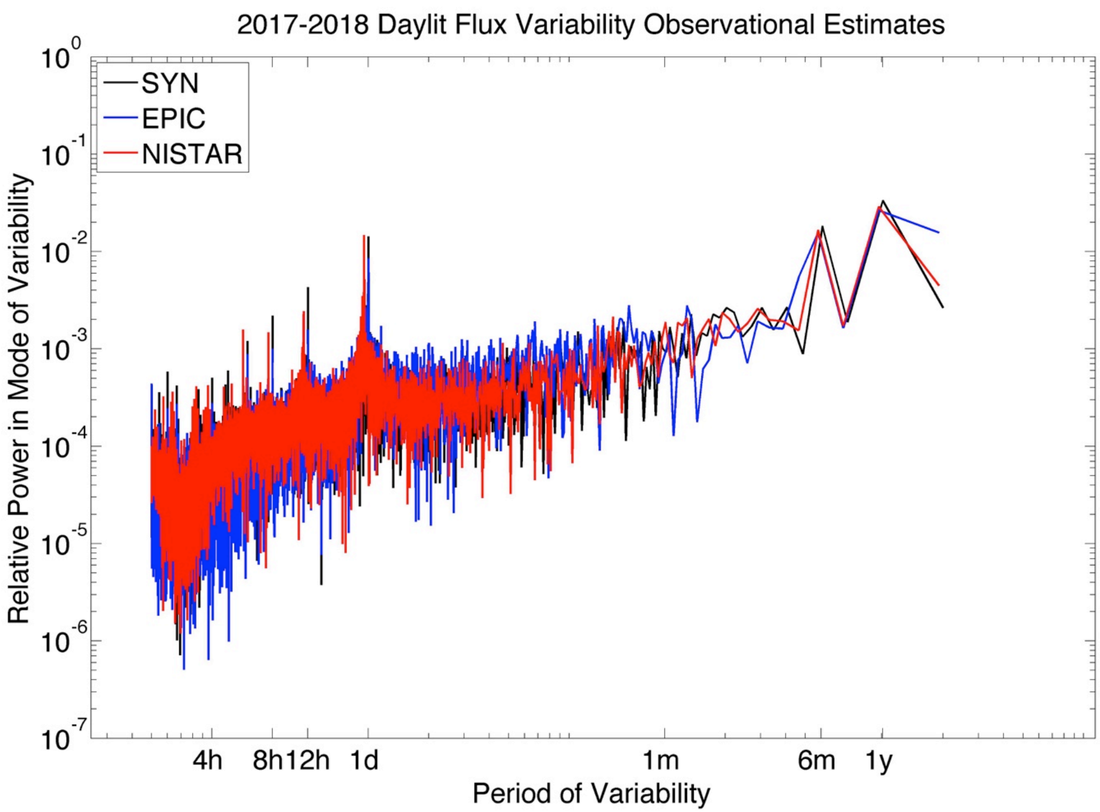
Observations of RSR Diurnal Variability

- RSR exhibits a marked diurnal cycle driven by differential land-surface albedo from Africa. Clouds also modulate this diurnal cycle



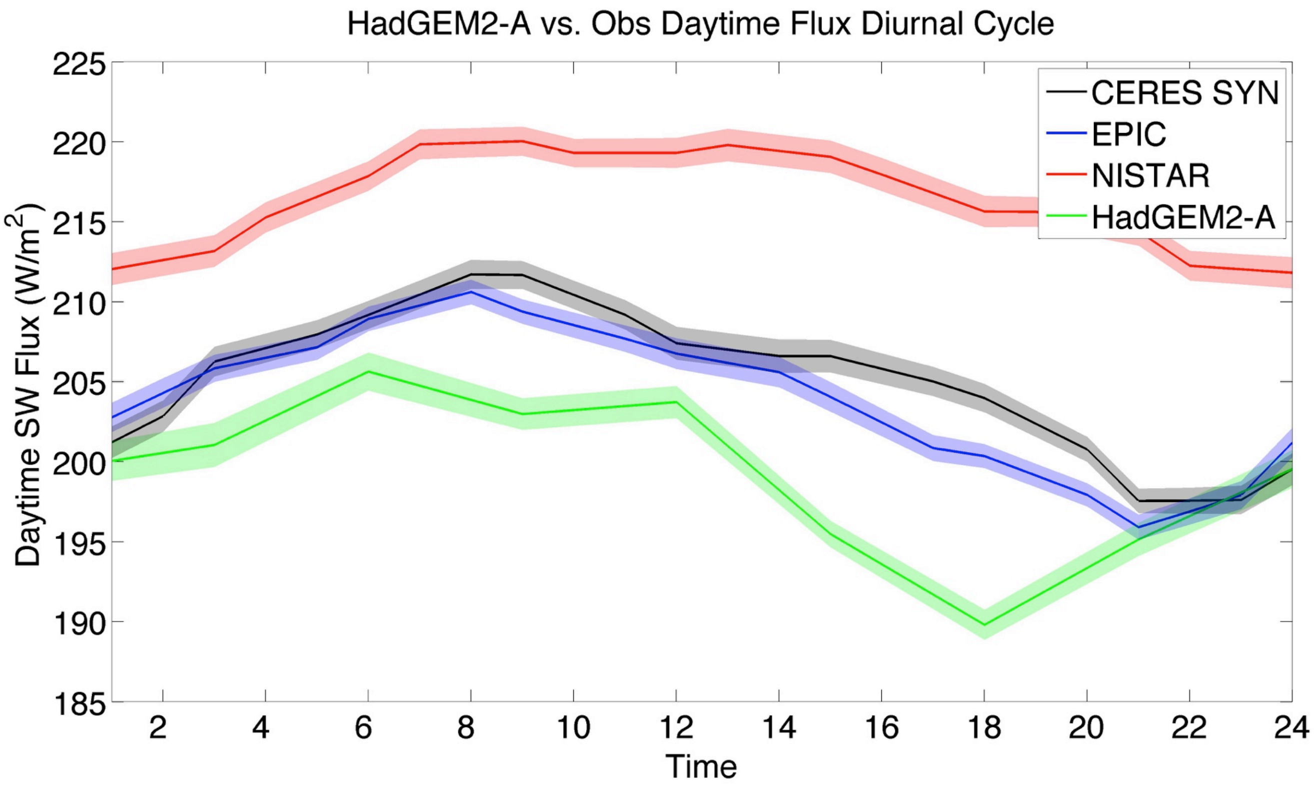
RSR Modes of Variability

- An analysis of the modes of variability in RSR from two years of observations from EPIC, NISTAR, and CERES SYN reveals similar variability in frequency between the 3 instrument estimates.
- The observations show that the diurnal-filling process chain does not have discernible biases.



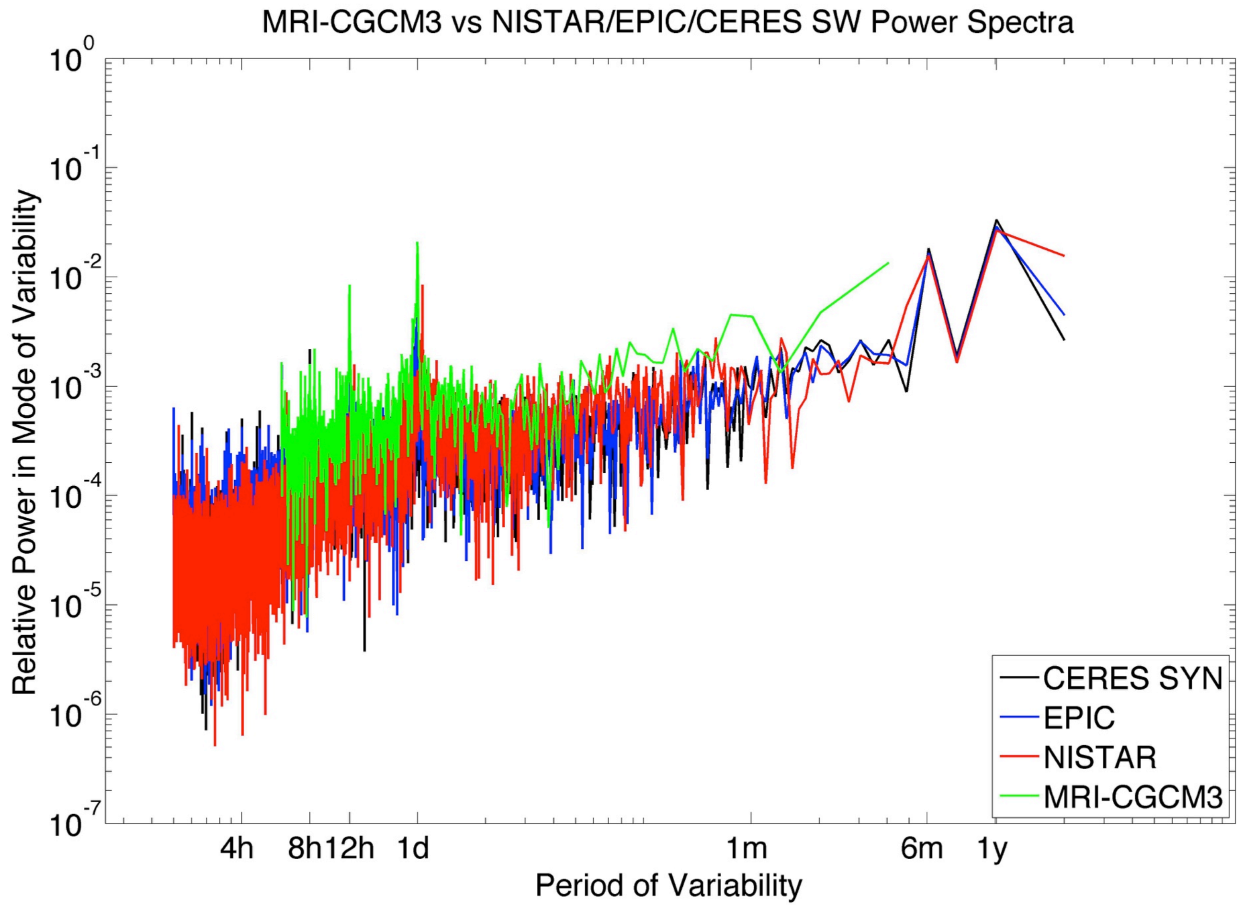
Obs vs Model RSR Diurnal Cycle

- With increased confidence in the diurnal cycle of RSR
- As part of the Coupled Model Intercomparison Project – Phase 5 (CMIP5), a number of models reported 3-hourly shortwave fluxes as part of CFMIP.
- Projecting model fluxes with the time-varying DSCOVR FOV shows systematic biases in model mean diurnal cycle that vary by model.



Obs vs Model RSR Diurnal Cycle

- Through frequency analysis with power spectral density curves, we can show the time-scales of variability in modeled RSR, and therefore show the path models use to achieve RSR interannual variability.

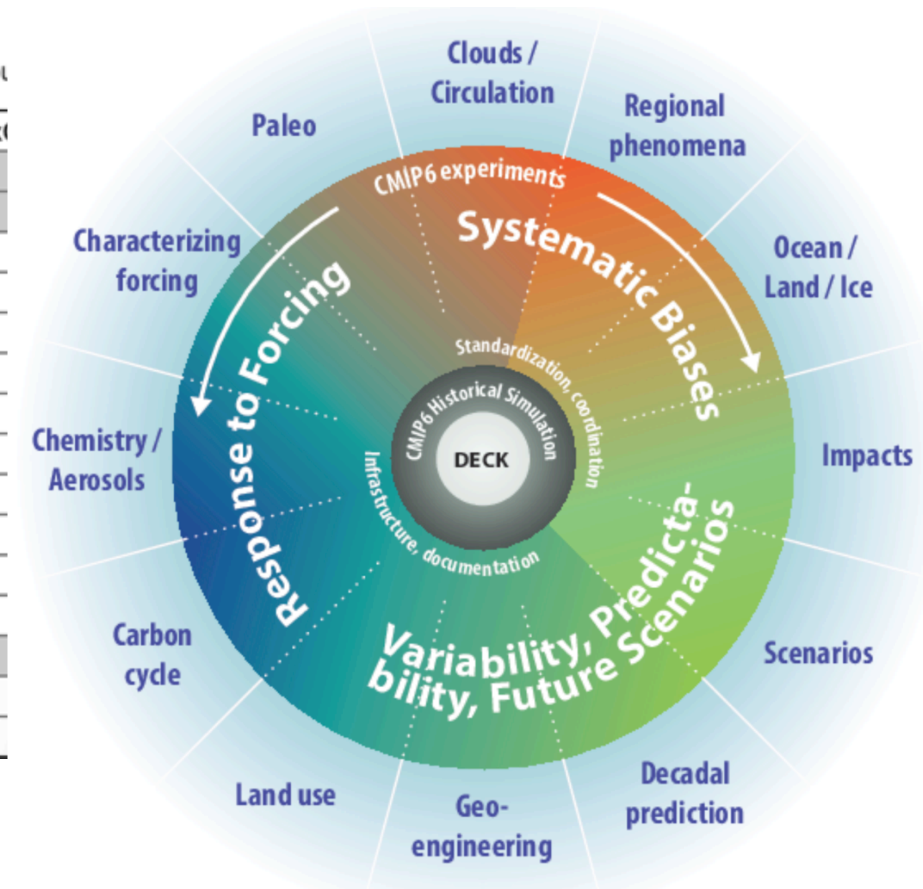


Examining CMIP6 Models

- The Coupled Model Intercomparison Project – Phase 6 (CMIP6) is underway, with many models having already reported results.
- Several experiments report TOA shortwave upwelling fluxes at hourly or sub-hourly intervals.

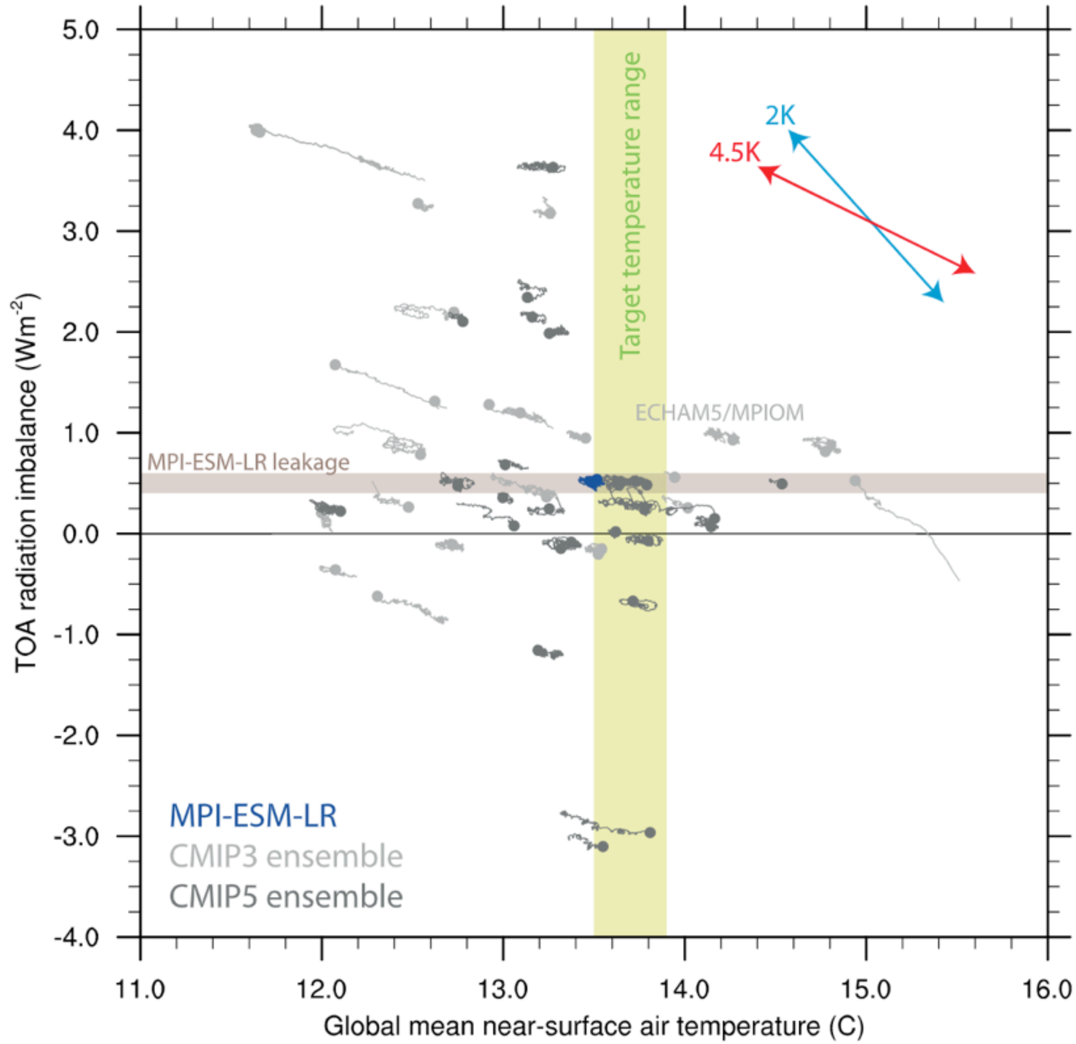
Number of models providing outpu

frequency	1pctCO2	abrupt-4x(	ntrol	piControl-spinup
1hr				
1hrCM				
3hr	9	8		
3hrPt	7	6		
6hr	1	2		
6hrPt	4	4		
day	14	15		
dec	2	2		1
fx	12	11		2
mon	21	21		2
monC	6	6		1
monPt	3	3		1
subhrPt				
yr	8	8		1
yrPt	1	2		



Model TOA Energy Balance

- Models are calibrated/tuned to achieve TOA energy balance on long time-scales.
- This process involves balancing a number of competing model performance goals by adjusted parameters to which models are sensitive but which are poorly or unconstrained.
- There is a question of whether this juggling act is getting the right answer for the wrong reason.



". . .But look: Four wrongs squared, minus two wrongs to the fourth power, divided by this formula, do make a right."

A Scientific Discussion on Tuning

- Only recently has the scientific literature started to discuss how tuning is undertaken at modeling centers.

THE ART AND SCIENCE OF CLIMATE MODEL TUNING

Frédéric Hourdin, Thorsten Mauritsen, Andrew Gettelman, Jean-Christophe Golaz, Venkatramani Balaji, Qingyun Duan, Doris Folini, Duoying Ji, Daniel Klocke, Yun Qian, Florian Rauser, Catherine Rio, Lorenzo Tomassini, Masahiro Watanabe, and Daniel Williamson

Tuning the climate of a global model

Thorsten Mauritsen,[1] Bjorn Stevens,[1] Erich Roeckner,[1] Traute Crueger,[1] Monika Esch,[1] Marco Giorgetta,[1] Helmuth Haak,[1] Johann Jungclaus,[1] Daniel Klocke,[2] Daniela Matei,[1] Uwe Mikolajewicz,[1] Dirk Notz,[1] Robert Pincus,[3,4] Hauke Schmidt,[1] and Lorenzo Tomassini[1]

Received 27 January 2012; revised 22 June 2012; accepted 2 July 2012; published 7 August 2012.

Geosci. Model Dev., 10, 3207–3223, 2017
https://doi.org/10.5194/gmd-10-3207-2017

Geoscientific Model Development
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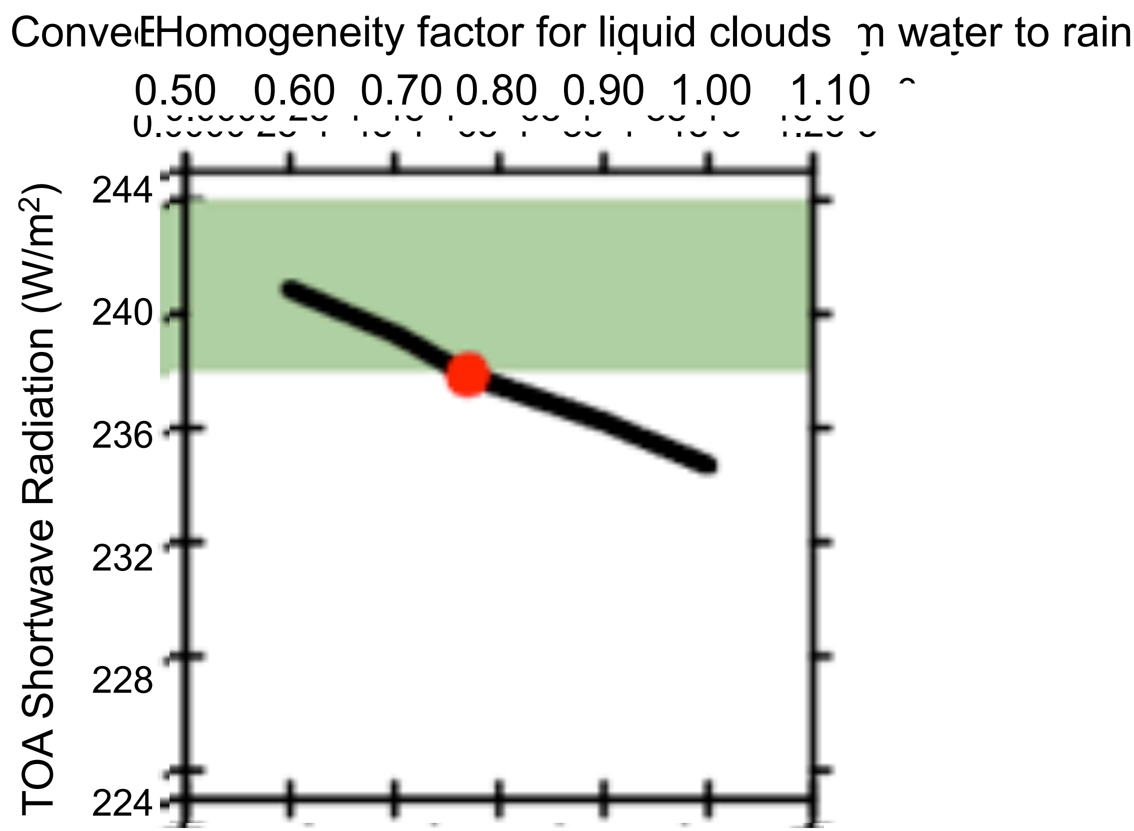
Practice and philosophy of climate model tuning across six US modeling centers

Gavin A. Schmidt[1], David Bader[2], Leo J. Donner[3], Gregory S. Elsaesser[1,4], Jean-Christophe Golaz[2], Cecile Hannay[5], Andrea Molod[6], Richard B. Neale[5], and Suranjana Saha[7]

[1]NASA Goddard Institute for Space Studies, 2880 Broadway, New York, USA
[2]DOE Lawrence Livermore National Laboratory, Livermore, California, USA
[3]GFDL/NOAA, Princeton University Forrestal Campus, 201 Forrestal Rd., Princeton, New Jersey, USA
[4]Columbia University, New York, New York, USA
[5]National Center for Atmospheric Research (NCAR), Boulder, Colorado, USA
[6]Global Modeling and Assimilation Office, NASA GSFC, Greenbelt, Maryland, USA
[7]Environmental Modeling Center, NCEP/NWS/NOAA, NCWCP College Park, Maryland, USA

More on the Tuning Process

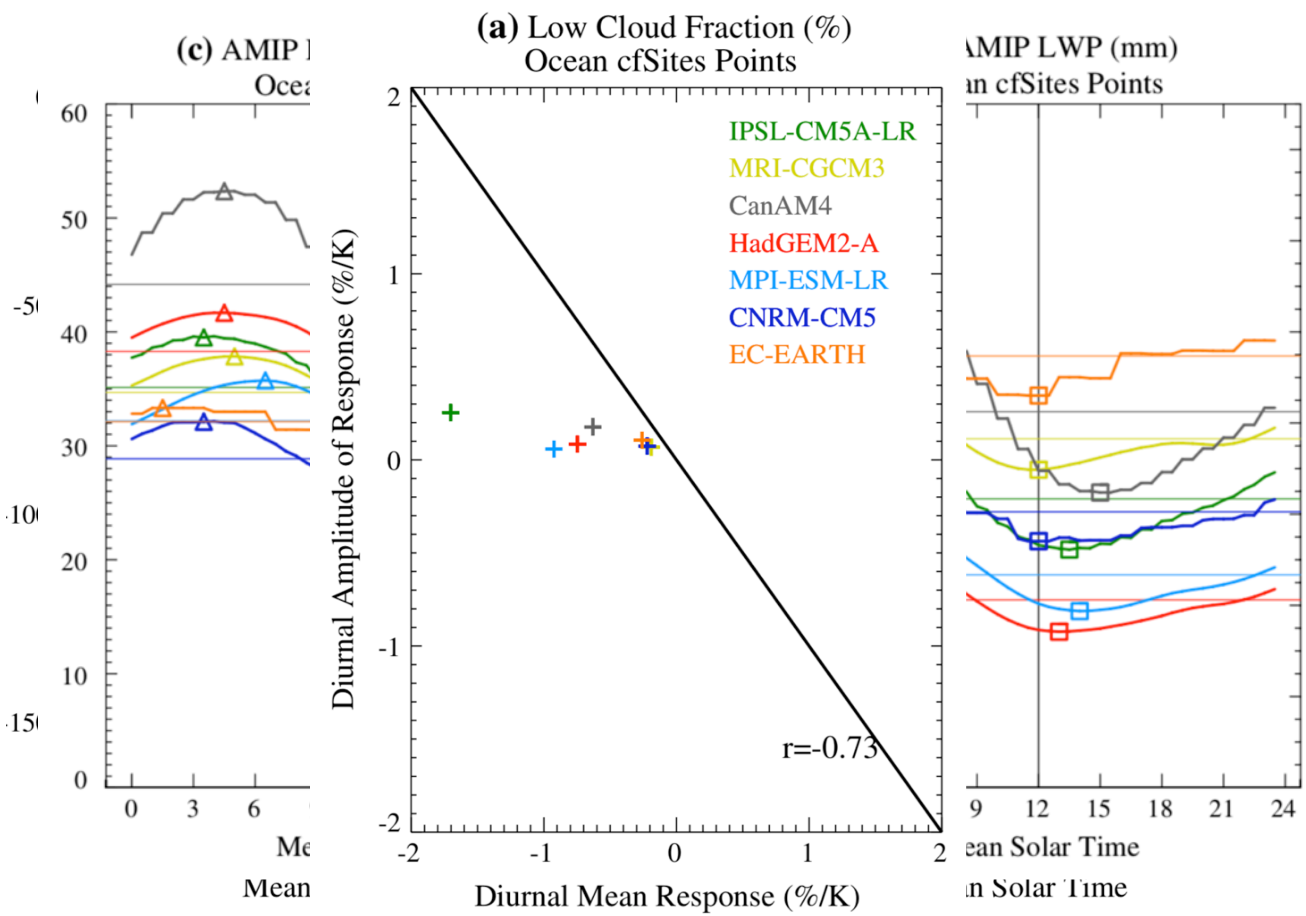
- Radiation, as a single number, is targeted for tuning. Shortwave is a key component of this and is affected, with many other tuning targets by tuning parameters.



Mauritsen et al, JAMES, 2012

Diurnal Cycle and Diurnal Mean

- The diurnal cycle of clouds is important for key uncertain cloud feedbacks, including those of the marine boundary layer.
- More analysis on the contributions of specific regions to the global daytime SW flux is needed.



Part I Summary of Temporal CRE Study

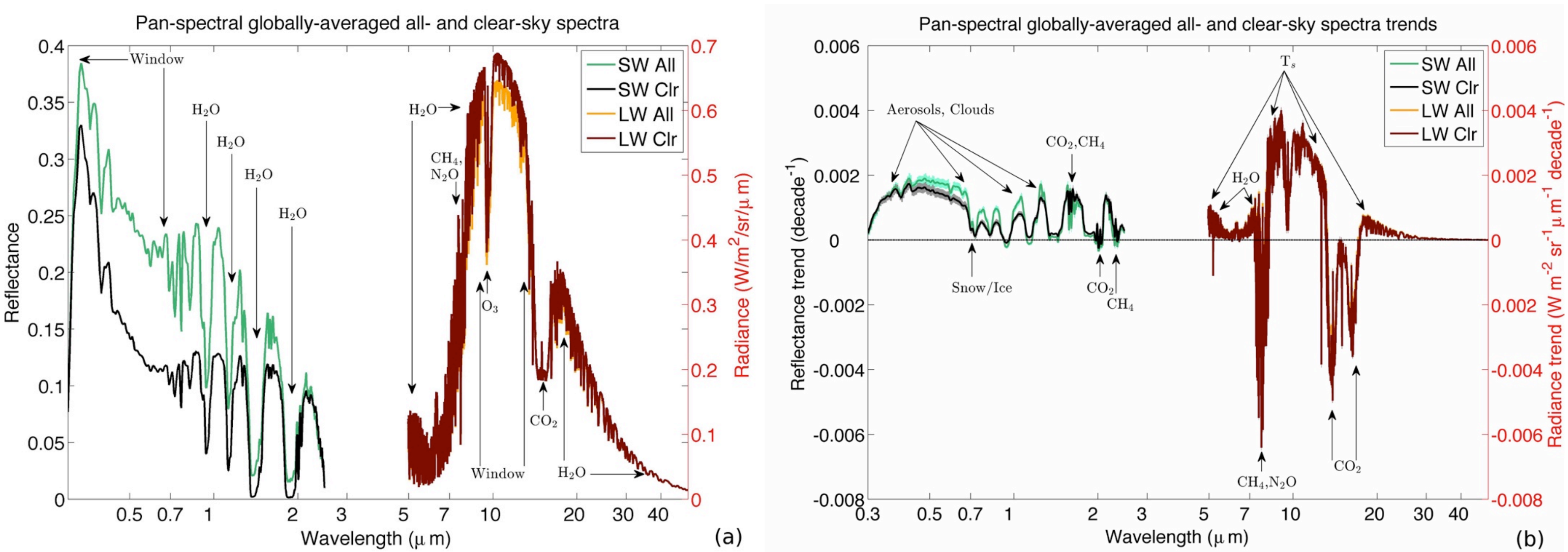
- For radiation budget observations, DSCOVR's distinguishing feature is its temporal frequency.

- SW flux estimates constructed from EPIC and NISTAR suggest that diurnal filling is not problematic for long-term estimates of SW fluxes.

- Frequency analysis can help constrain not just long-term SW fluxes, but how they are achieved by models.

Part II: Spectral Shortwave Climate Signals

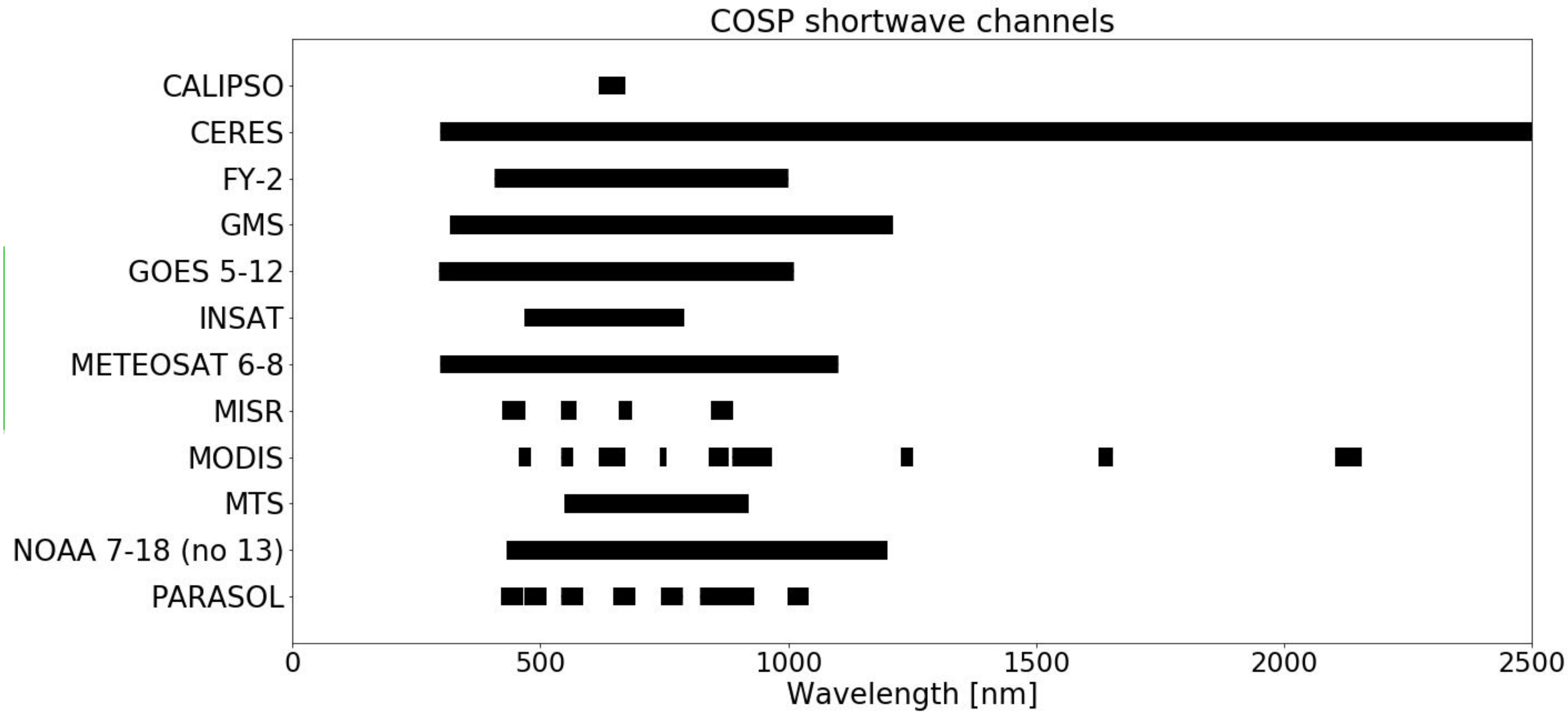
- The CERES instrument has been making long-term observations of broadband albedo, but there are numerous surface and atmospheric features that can simultaneously affect albedo.
- The classic example is a reduction in sea-ice can be counteracted by increasing clouds.
- The spectral dimension of albedo remains relatively unexplored, but has lots of information about the surface condition, condensates, and gases.



Feldman et al., Journal of Climate, 2015

Observing System Simulation Experiments

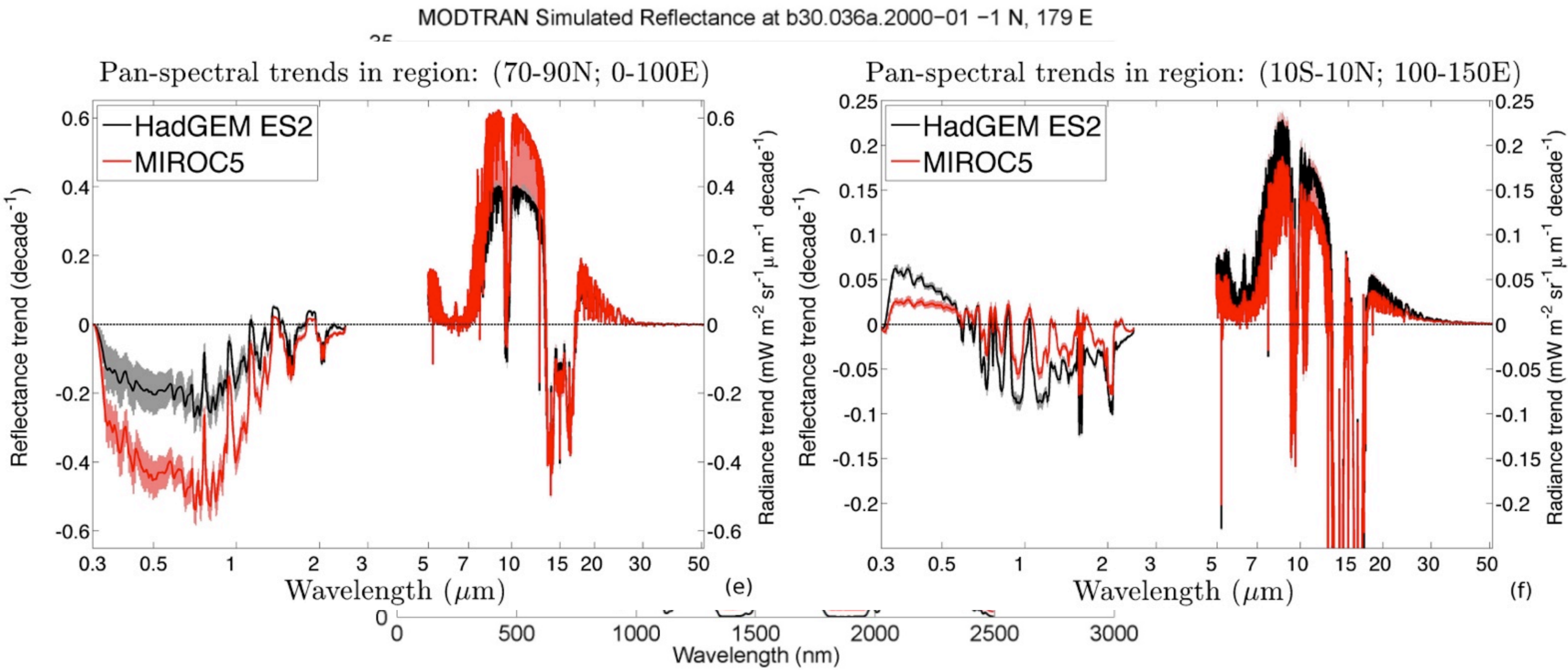
- There are many fewer hyperspectral shortwave TOA measurements as compared to narrow-band or broadband measurements. However, CLARREO Pathfinder is coming soon …
- To understand long-term signals from such instruments, we have built an offline instrument emulator in ingest CMIP data, which resolves from 300 to 2500 nm at 5 nm resolution.



Feldman et al, JGR, 2011; Feldman et al, GMD, 2015; Feldman et al, JGR, in Review

OSSE Capabilities and Outputs

- The OSSE uses MODTRAN to produce spectrally-resolved radiance and flux values at the TOA.
- By being coupled to CMIP models, it can be used to characterize the spectral signals associated with model realizations of climate change, and potentially for differentiating models and obs.



Feldman et al, GMD, 2015

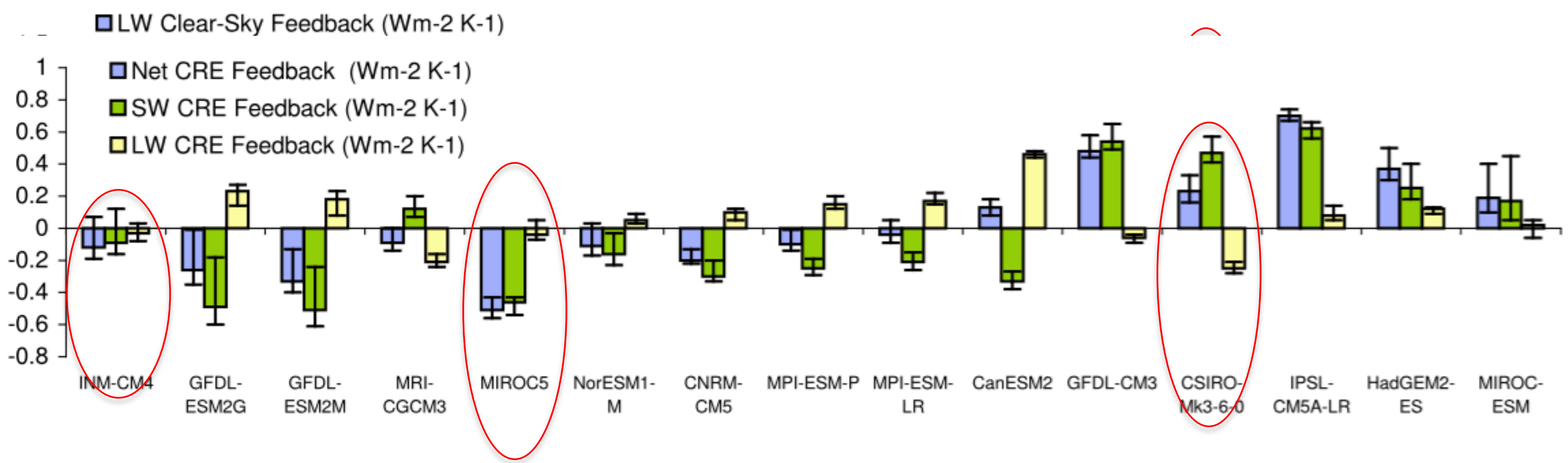
OSSE Applications to CMIP5

- Based on (relatively) consistent outputs from CMIP5, we can produce centennial-length clear-sky and all-sky spectral albedo calculations.
- We have applied this capability to 3 distinct climate models that roughly span the range of diagnosed model sensitivities, for the RCP8.5 emissions scenario.
- The cost of these calculations is extreme: thousands of CPU-hours per month of simulation.

Model Name	Diagnosed ECS (° K/2xCO2)
CESM1-CAM5	4.10
CanESM2	3.69
CSIRO Mk3-6-0	4.08
MIROC5	2.72
MRI-ESM1	2.10
MRI-CGM3	2.60
inmcm4	2.08

OSSE Applications to CMIP5

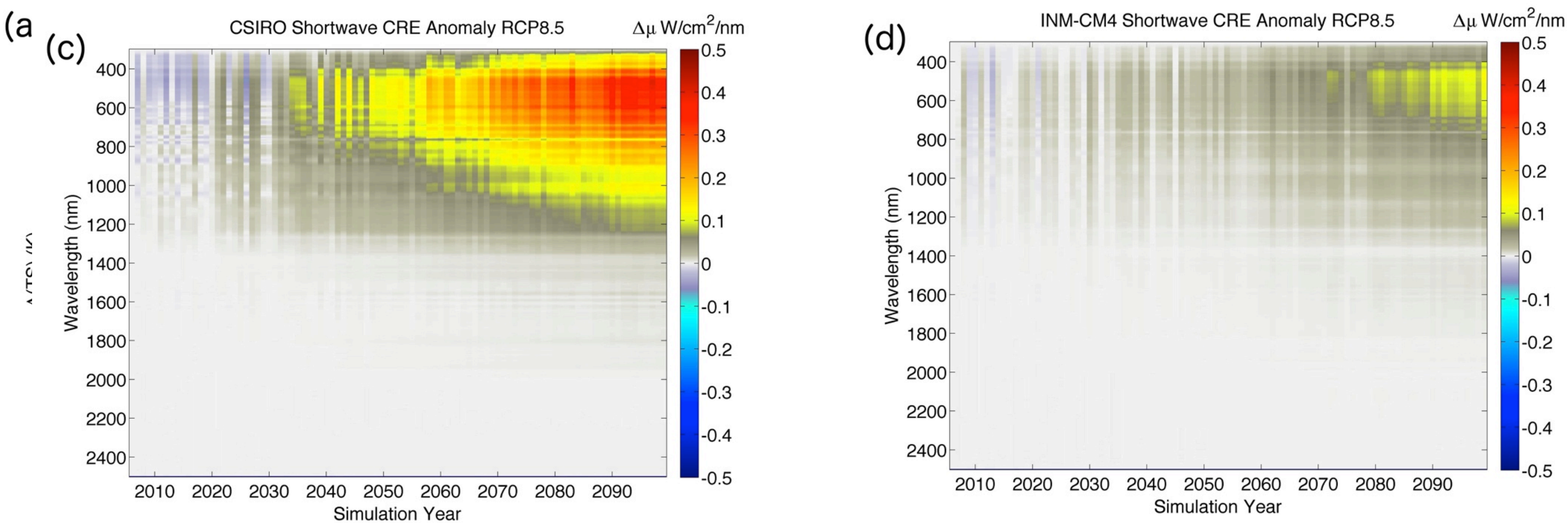
- The 3 models we chose exhibit very similar diagnosed clear-sky feedbacks:
  - INM-CM4: LW = -1.98 $W/m^2/K$ SW = +0.67 $W/m^2/K$
  - MIROC5: LW = -1.85 $W/m^2/K$ SW = +0.84 $W/m^2/K$
  - CSIRO Mk3-6-0: LW = -1.70 $W/m^2/K$ SW = +0.84 $W/m^2/K$
- But dissimilar CRE feedbacks.
  - INM-CM4 net CRE feedback is small. SW and LW are negative.
  - MIROC5 net CRE feedbacks are on the high but negative, SW is negative and LW is negative.
  - CSIRO Mk3-6-0 net CRE feedback are mid-range positive, SW is positive and LW is negative.



Andrews et al, GRL, 2012

Spectral Signals in the Broadband

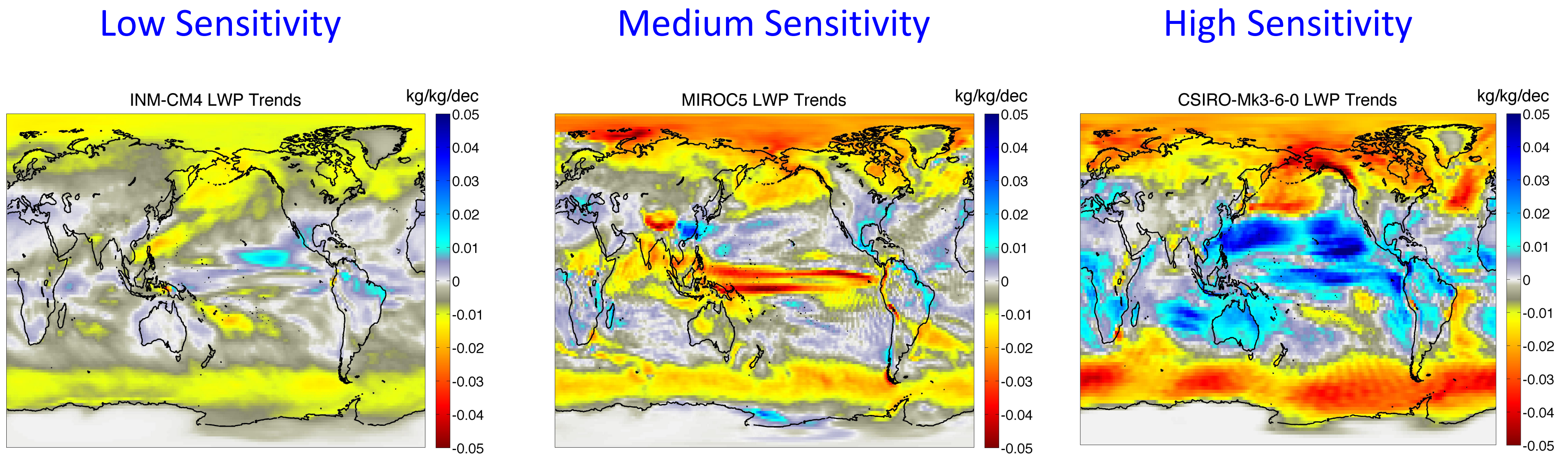
- In the RCP8.5 emissions scenario, model gross temperature responses differ significantly, and the CRE response differs in sign between the high- (CSIRO) and low-sensitivity (INM) models.
- We see the emergence of anomalies in spectral CRE, primarily at wavelengths below 1300 nm.



Feldman et al, JGR , In Review

Geophysical Variable Trends

- To decompose the global signal, let's first look at how variables that impact the shortwave energy budget change between the 3 models.
    - PRW spatial trend patterns similar in shape, differ in magnitude.
    - Cryospheric changes most severe in medium sensitivity model.
    - Cloud macroscopic property trends very dissimilar between models.

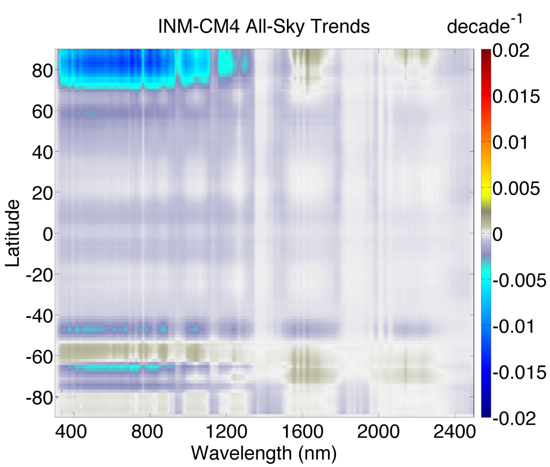


Andrews et al, GRL, 2012

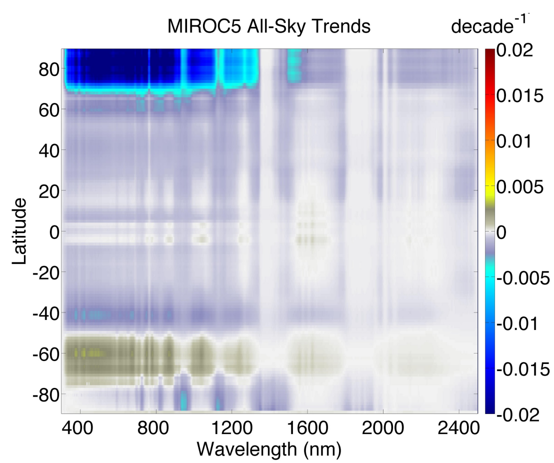
What is the Info in Shortwave Spectral Obs?

- The clear-sky signals that emerge from the models are dominated by associated changes in the cryosphere at high-latitudes.
- Slight trends evident in the water-vapor overtone bands at all latitudes.
- Cryospheric signals are muted in all-sky trends.
- Low-latitude all-sky trends are significant, but are also spectrally-correlated.

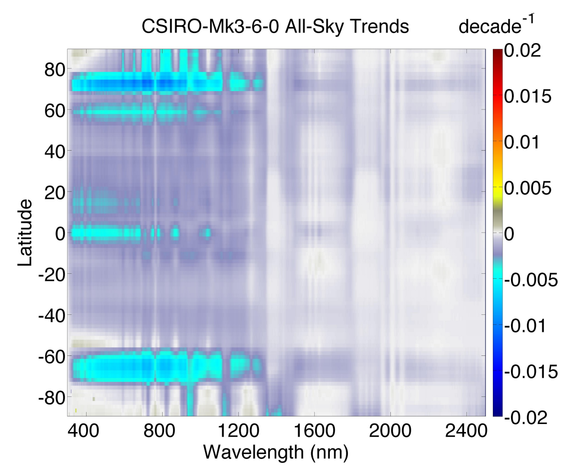
Low Sensitivity



Medium Sensitivity



High Sensitivity

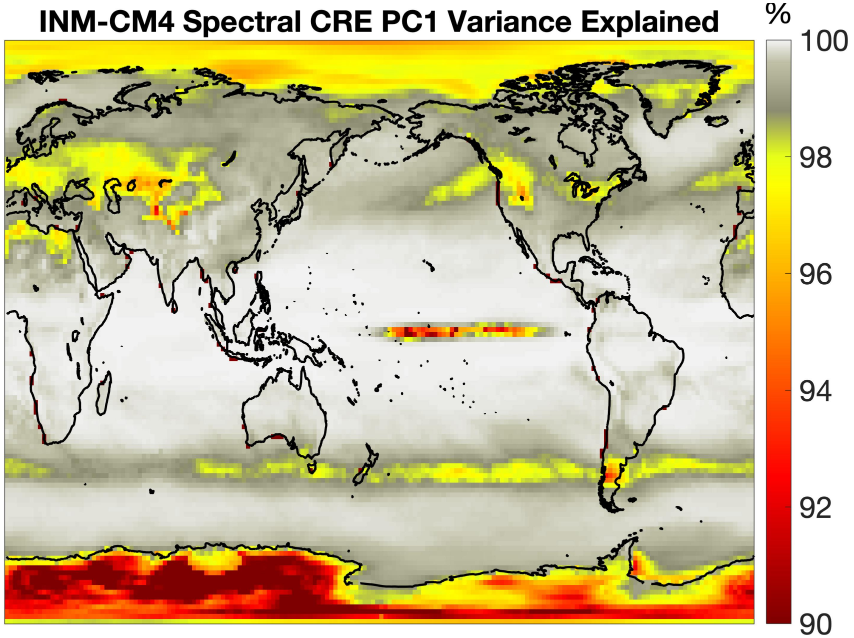


Andrews et al, GRL, 2012

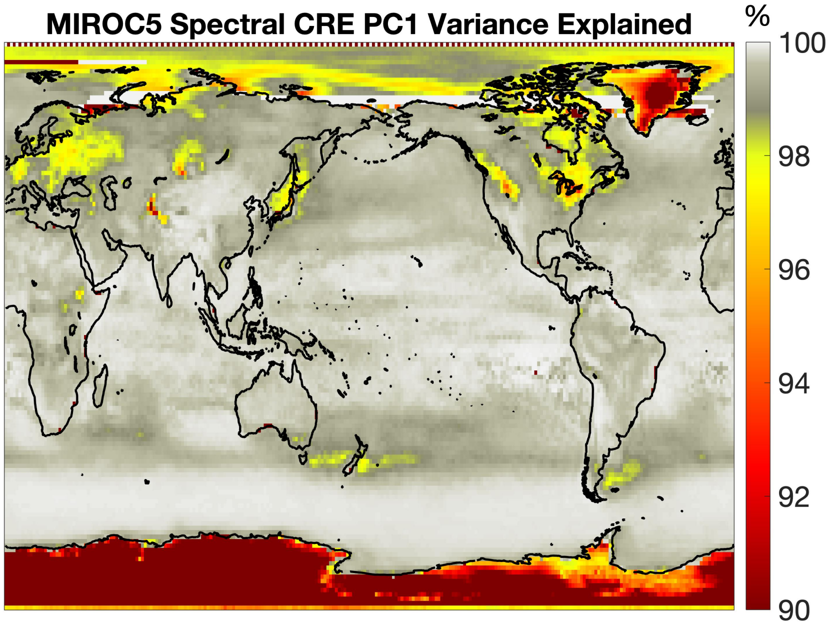
What is the Info in Shortwave Spectral Obs?

- Is there extra information in shortwave spectral measurements?
- We perform PCA analysis on the OSSE spectral albedo simulations. If the fraction of variance explained by the first PC is high, there is little ambiguity in broadband observations, and the factors that contribute locally to albedo are stationary.
- For 2 of the models, processes contributing to albedo are stationary. However, for the cryosphere (both high-lat and high-alt), they are not.

Low Sensitivity



Medium Sensitivity



Andrews et al, GRL, 2012

Part II Summary of Spectral CRE Study

- There are competing surface and atmospheric state conditions that
- With a SW hyperspectral OSSE, we can see if there could be ambiguity in CRE trends observed from CERES.
- We find that, at low latitudes, there is a consistent explanation for all of the mechanisms that control albedo at a given location at decadal time-scales.
    - Little chance for error cancellation.
- There is ambiguity in albedo-controlling mechanisms in the cryosphere.